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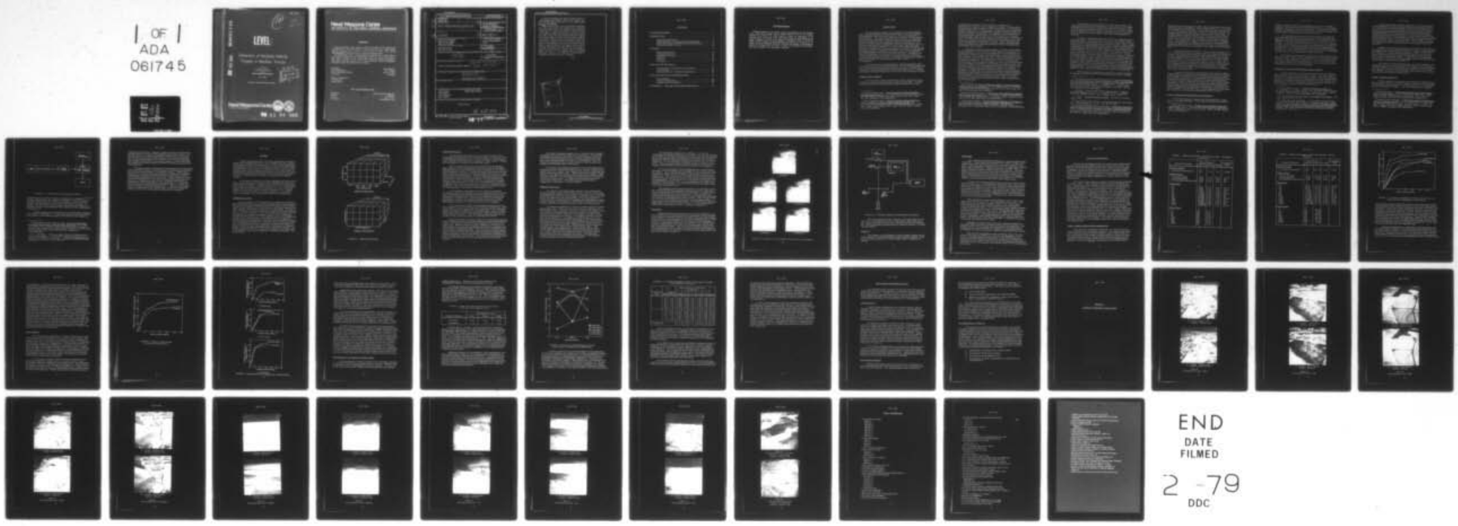

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Detection of Multiple-Vehicle Targets in Realistic Terrain

by
Lynn A. Olzak
Hughes Aircraft Company
for the
Systems Development Department

JULY 1978

Approved for public release; distribution unlimited.

Naval Weapons Center
CHINA LAKE, CALIFORNIA 93555

Naval Weapons Center
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FOREWORD

This report documents a study conducted in 1977-78 by the Hughes Aircraft Company for the Naval Weapons Center, China Lake, California. The work was carried out under a target acquisition program supported by the Naval Air Systems Command under Airtask A03A3400/008B/7F55-525-000, with Jeffrey D. Grossman as the technical monitor.

The Naval Weapons Center is conducting analysis and experimentation on several aspects of target acquisition, including detection and identification of targets by airborne sensors as well as direct vision. An algorithm has been developed which relates target acquisition performance to weapon delivery. This report describes a study to improve the data base required by the algorithm. The program to further expand this data base is continuing.

Approved by
M. M. ROGERS, *Head*
Systems Development Department
20 July 1978

Under authority of
W. L. HARRIS
RAdm., U.S. Navy
Commander

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(U) The interactive effects of target and background characteristics upon visual target acquisition were investigated. Five multiple-target conditions that varied in number and configuration (single tank, group of 3 tanks, convoy of 3 tanks, group of 9 tanks, and convoy of 9 tanks) were embedded into oblique aerial photographs of real terrain. Proximity of the targets to major roads in each scene was manipulated to assess the effects of local context on detection performance. Terrain complexity was evaluated by a subjective scale of scene heterogeneity. Results from a visual search experiment indicated that performance improved as the number of tanks comprising a target increased. An interaction between number of targets and proximity to roads suggested that local context is a relatively more important performance predictor when searching for single tanks than when searching for multiple targets. The heterogeneity measure was found to be an inadequate predictor of detection performance. An approach for the development and implementation of valid predictors of detection performance was suggested.

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ACKNOWLEDGEMENT

Contractual support for the reported research was provided by the Naval Weapons Center, China Lake, California, Contract Number N00123-77-C1134. J. D. Grossman monitored the contract. The author wishes to express her appreciation to Mr. Grossman and R. A. Erickson of the Naval Weapons Center for their suggestions and support throughout the course of this program. M. Hershberger and Dr. L. Scanlan of Hughes Aircraft Company provided significant contributions to all aspects of the program, and their management assistance is gratefully acknowledged. The photographic expertise of D. Craig and the aid of Ms. A. Agin in the preparation of the literature review were invaluable to the completion of this study.

INTRODUCTION

The successful prediction of visual target acquisition depends both on the identification of relevant parameters and on the application of an algorithm which combines measures of these parameters in a meaningful way. For such an algorithm to be useful in a field situation, it must contain components which are easily evaluated and integrated. Numerous studies have been conducted to isolate important characteristics on the basis of their independent effects on performance, and several models have been developed in which these parameters are combined into a predictive equation.[1,2] Many of the models developed, however, are dependent on exacting physical measurements and complex integrative schemes. Although such models may make a contribution to the understanding of the target acquisition process, at their present level of development, they are not useful in the field. In addition, the current models tend to be limited in scope and generality; most have employed abstract stimuli and few incorporate multiple target configurations, terrain effects, or interactions of target and scene characteristics.

A review of recent experimental and modeling literature relevant to the current study is provided below. Several different approaches are summarized; the major areas of focus have been: a) target characteristics, b) overall analysis of background characteristics, c) elemental analysis of background features, and d) the target acquisition process.

TARGET CHARACTERISTICS

In most of the current mathematical models, targets have been modeled as separate elements against uniform backgrounds. A single target has been the most frequently employed element and has been

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[1] Naval Weapons Center. Target Acquisition Model Evaluation: Final Summary Report, by C.P. Greening, Autonetics Division, Rockwell International. China Lake, Calif., NWC, June 1973. (NWC TP 5536, publication UNCLASSIFIED.)

[2] Naval Weapons Center. Target Acquisition Model Evaluation: Part 2. A Review of British Target Acquisition Models, by C.P. Greening, Autonetics Division, Rockwell International. China Lake, Calif., NWC, August 1974. (NWC TP 5536, Part 2, publication UNCLASSIFIED.)

generally characterized in terms of shape or a geometric approximation, apparent size, or apparent contrast.[3] Although these parameters have been found to be useful when targets are presented in isolation against uniform backgrounds, Scanlan[4] has demonstrated that detection performance is significantly degraded by the presentation of targets in realistic backgrounds. For example, while detection time for single targets in uniform backgrounds averaged 1 to 2 seconds, identical targets within realistic scenes required between 20 and 40 seconds. It is clear from this time difference that targets in real world situations need to be investigated in context. While independent measures of target features have some predictive power, measures that capture the interactive relationships between target and background should add to this capability.

Zaitzeff[5] has addressed this problem in a study which included absolute physical measures of target characteristics, measures of background features, and several variables that incorporated the relational aspects between targets and backgrounds. Using a factor analytic technique, seven parameters which contributed significantly to the prediction of target detection performance were isolated from a set of 15 potential parameters. Two factors were found to specify target characteristics (target length and width), two were concerned with background complexity (heterogeneity and brightness element counts), and the remaining three measured target-background relationships (target contrast, detail contrast, and ambiguity or number of confusion elements). A ridge regression analysis using the seven variables as predictors accounted for 79 percent of the variance; target and target-background interactions were found to be the most powerful predictors, while background complexity measures were found to have the least predictive value. It was suggested that further research would be necessary to establish the relationship between scene complexity and search effectiveness.

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[3] Naval Weapons Center. Review of Mathematical Models of Air-to-Ground Target Acquisition Using TV and FLIR Sensors, by A. D. Stathacopoulos, H. F. Gilmore and G. Rohringer, General Research Corporation. China Lake, Calif., NWC, January 1976. (NWC TP 5840, publication UNCLASSIFIED.)

[4] Hughes Aircraft Company. Target Acquisition Model Development: Effect of Realistic Terrain, by L.A. Scanlan, Display Systems Department, Hughes Aircraft Company. Culver City, Calif., December 1976. (HAC TP P76-484, publication UNCLASSIFIED.)

[5] The Boeing Company. Target Background Scaling and its Impact on the Prediction of Aircrew Target Acquisition Performance, by L.P. Zaitzeff, Aerospace Group, Boeing Company. Seattle, Wash., December 1971. (AD737693 D180-14156-1, publication UNCLASSIFIED.)

The results of research efforts in which single targets were employed demonstrate that although target characteristics are useful parameters in the prediction of detection performance, their interaction with background characteristics must also be considered. There is some evidence, however, that the contribution of scene characteristics is diminished when multiple, rather than single targets are employed.

The term "multiple targets" may refer to two different types of acquisition tasks. The first is actually a search for multiple single targets in that several targets are widely spaced within a scene. Detection is similar to that expected for a sequence of single tanks, although Whittenburg has reported that detection of one target may inhibit search and detection of other targets in this situation.[6] The second type of multiple target search occurs when targets are grouped closely enough to fall within the observer's foveal or parafoveal regions, which are generally taken to be about 1 and 5 degrees, respectively.[7] Gestalt theory and research provide evidence that such groupings are perceived as a single pattern, which is easier to detect than a single target because of increased angular subtense which must vary directly with number. Up to some limiting area (beyond which the parafoveal region is exceeded), patterns perceived as a unit should grow increasingly easy to detect as the number of single elements within each increases.[7,8] Some support for this is found in laboratory studies employing abstract multiple targets. It has been reported that as number and similarity of targets increase, detection performance increases correspondingly.[9]

Further evidence supporting this prediction has been reported by Hilgendorf and Milenski.[10] A terrain board was used to simulate

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[6] U.S. Army Aviation Human Research Unit. Research Memorandum: Research on Human Aerial Observation Part III: Summary Data from Tactical Field Tests, by J.A. Whittenburg, C. Barlow, K.L. Deveney, R.D. Warne, and A.L. Schreiber, U.S. Army Aviation Human Research Unit, Fort Rucker, Alabama, July 1960. (AD 452 708, publication UNCLASSIFIED.)

[7] Le Grand. "Measurement of the Visual Stimulus," in Handbook of Perception, ed. by E.C. Carterette and M.P. Friedman. New York, Academic Press, 1975. Chapter 2, pp. 25-55.

[8] L. Zusne. Visual Perception of Form. New York: Academic Press, 1970.

[9] W.R. Uttal and T.E. Tucker. "Complexity effects in form detection," Vision Research, Vol. 17, 1977, pp. 359-365.

[10] Aerospace Medical Research Laboratory. SEEKVAL project IA1: Effects of Target Number and Clutter on Dynamic Target Acquisition, by R.L. Hilgendorf and J. Milenski, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, January 1976. (AD A024 166, publication UNCLASSIFIED.)

different target numerosity and clutter density conditions for the Joint Task Force project SEEKVAL. Group configurations of 1, 3 or 9 tanks were placed in close proximity to a varying number of clutter objects (0, 30 or 60 trees per unit area). Under all conditions of clutter, the multiple target groups were easier to detect than a single target. Although neither the clutter main effect nor the target number-clutter interaction was significant, clutter effects appeared to be more pronounced with a single tank than with either of the multiple configurations. The results of this study confirm the numerosity expectation based on Gestalt theory; in addition, some evidence is provided that background effects interact with target numerosity, with background effects being relatively more important in the single-target acquisition task.

A study reported by Barnes[11] in which number of targets (1, 4 or 7), configuration (linear or random), S/N ratio, and target-background contrast were manipulated revealed significant effects due to target number, configuration and contrast. The number effect was largely due to a difference between the single target and the multiple targets, as no differences were found between four and seven targets. Configuration was found to interact with contrast. Linear configurations were significantly easier to detect than random patterns when the targets were dark, but no difference was found when they were light. S/N ratio did not have an effect, which was attributed to the restricted range used in the experiment.

In general, the results of experiments which include multiple targets suggest that background characteristics become less important as the number of multiple elements comprising the target increases. For predictive purposes, the measurement of these background characteristics will be particularly important for single target situations, where their relative contribution is greater than with multiple targets. Although the evidence points out the importance of these background characteristics, the lack of significant results when background complexity is manipulated suggests that a good measure of complexity is not yet available. In the next section, several approaches to the problem of background complexity measurement will be reviewed.

GLOBAL MEASURES OF BACKGROUND CHARACTERISTICS

Several psychological scales have been developed for rating scenes on overall complexity. In the study described in the previous

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[11] Naval Weapons Center. Display Size and Target Acquisition Performance, by M.J. Barnes, Systems Development Department, NWC. China Lake, Calif., January 1978. (NWC TP 6006, publication UNCLASSIFIED.)

section, Zaitzeff[5] employed a heterogeneity scale which required subjects to rate scenes in terms of overall busyness (i.e., variations in texture, brightness, objects and spacing). The significance of this measure was marginal and its inclusion in the regression equation contributed little to the predictive power of the function.

The heterogeneity measure was also employed in a study by Ciavarelli, Wachter, and Lee[12] and was found to be reliable among subjects, and to consistently separate desert, rural and urban scenes. Differences among the intermediate rural scenes, however, were minimal. A similar result was found by Scanlan,[4] who also employed a subjective complexity rating scale in the classification of aerial terrain photographs. Extremely simple and extremely complex backgrounds were widely separated on the scale and predictive of detection performance. Intermediate values showed a high degree of variability, and were therefore not included in the detection study.

The results of these studies suggest that a global rating scale is adequate to differentiate extreme differences in terrain, but is not sensitive to the finer differences found among most rural terrains, which nevertheless affect detection performance. To isolate some of these less obvious differences, backgrounds have been measured in a more elemental manner by several investigators.

ELEMENTAL ANALYSIS OF BACKGROUND CHARACTERISTICS

A large collection of elements in background scenes that may affect detection performance have been isolated. The most useful of these fall into measurements of texture, clutter, and context features. Texture is generally measured by photometric methods, and has been found to be a significant factor when measured near the target area.[13] It may also be useful in classifying terrain types[14] and has been used as a descriptor in overall background analyses.[12,5]

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[12] Naval Weapons Center. Terrain Classification Study, by A. Ciavarelli, L. Wachter, and W. Lee. Research and Engineering Division, Boeing Aerospace Company. China Lake, Calif., NWC, May 1975. (NWC TP 5766, publication UNCLASSIFIED.)

[13] L.M. Biberman (ed.) Perception of Displayed Information. New York: Plenum Press, 1973.

[14] J. Weszka and A. Rosenfeld. "A comparative study of texture measures for terrain classification." In Proceedings of the conference on Computer Graphics, Pattern Recognition, and Data Structure of the Institute of Electrical and Electronics Engineers Computer Society. New York: Institute of Electrical and Electronics Engineers, 1975. Pp 62-64.

Clutter and context elements categorize scene characteristics into those that share visual features with the target and those that do not. Compared to the target, clutter elements are of similar size, contrast, color, or shape; their effect on the observer is to increase processing demands and therefore degrade detection performance. Context elements, on the other hand, do not share features with the target and may include elements such as roads, lakes, treelines, and steeply graded terrain. Context elements serve to decrease processing time by acting as cues to areas which may contain targets or cues to areas which are unlikely to contain targets. The net effect of context is to facilitate an active search process by reducing the area to be searched.

Clutter has been both specifically manipulated[11] and measured by counting the number of elements present in a natural scene that might be confused with a particular type of target.[12] While it seems likely that clutter has a reliable effect on detection performance, the functional relationship between clutter and target detection performance has not yet been adequately defined. Clutter has been incorporated, nevertheless, into at least one mathematical model in the form of a subjective rating of total amount of clutter.[15]

The effects of context elements are not yet well understood, but preliminary analyses of eye-movement data obtained while observers searched natural terrain indicate that search patterns are both spatially and temporally correlated with particular context elements.[16] However, further research is necessary before the elements will be useful in the prediction of detection performance.

TARGET ACQUISITION PROCESS

Another approach to the prediction of detection performance has been to model a system in which the outside world is the primary source of information and the operator is a terminal processor. A simplified system is illustrated in Figure 1, and is an example of the multiple

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[15] Rand Corporation. Target Acquisition through Visual Recognition: An Early Model, by H.H. Bailey, Rand Corporation. Santa Monica, Calif., Rand Corporation, September 1972. (Technical Report P-4918, AD-A030 699, publication UNCLASSIFIED.)

[16] Hughes Aircraft Company. A Behavioral Model of Target Acquisition in a Realistic Terrain, by L.A. Scanlan and A.K. Agin, Display Systems Department, Hughes Aircraft Company. Culver City, Calif., Hughes Aircraft Company, February 1978. (P78-70, HAC Ref No. D8983, publication UNCLASSIFIED.)

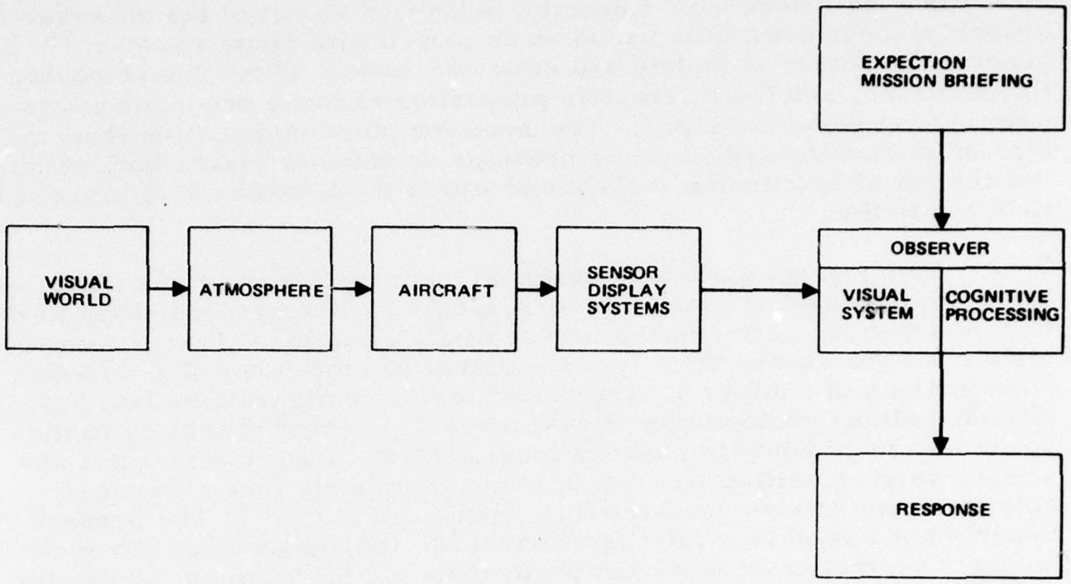

FIGURE 1. A Simplified Target Acquisition Model.

component process models frequency employed in this approach.[1, 3, 4, 17] Realistic backgrounds and targets are elements in the visual world, but intervening components such as atmosphere, aircraft, sensor, display, and peripheral visual systems may modify this input. In addition, this information may be further modified by the observer. In a dynamic system, this information may interact with the modifications of the observer.

Modeling efforts have concentrated on the intervening components of the system. Atmosphere,[1, 3] the visual system,[18] and sensor display systems[3] have all been modeled to the extent that their physical

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[17] Martin Marietta Aerospace Company. Air-to-Ground Target Acquisition Source Book: A Review of the Literature, by D. Jones, M. Freitag, and S. Collyer, Martin Marietta Aerospace Company. Orlando, Fla., Martin Marietta Aerospace Company, September 1974. (Technical Report DR 12 470, AD-A015 079, publication UNCLASSIFIED.)

[18] A.D. Schnitzer. "Theory of spatial-frequency filtering by the human visual system, I. Performance limited by quantum noise, II. Performance limited by video noise." Journal of the Optical Society of America, 1976, vol. 66, pp. 608-625.

states may be measured. Recently, a Markov model of the observer's search process over time has been employed with some success.[16] In general, however, complete and effective models of the visual world, the observer, and the interactive properties of these two components have not yet been developed. The need for more information from the type of studies described in the previous sections is clear, both within the context of processing models and within the framework of practical field prediction.

The present study was designed to investigate both the independent and the interactive effects of several target and background characteristics on detection performance in a realistic situation. Target characteristics were experimentally manipulated by embedding five different combinations of number of targets and target configurations into low altitude oblique photographs of real terrain. Target proximity to major roads was manipulated to assess local context-target interactions and scenes were classified into one of three complexity levels based on heterogeneity ratings performed in a previous study.[12] The present experiment was in part intended to evaluate the adequacy of this measure for prediction of detection performance. Although an integrative model is not developed in the current study, an approach toward the goal of an easily used, valid prediction algorithm is suggested.

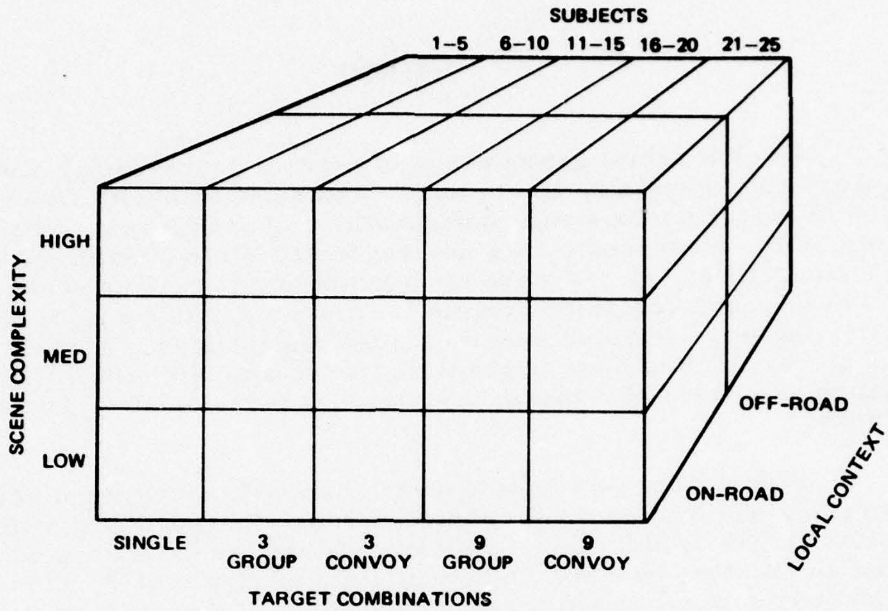
METHOD

Twelve aerial photographs of terrain representing a variety of background complexity levels were each embedded with five combinations of target number and configuration. Three levels of background complexity, measured by the heterogeneity scale previously developed by Ciavarelli et. al.,[12] were each represented by four scenes. Two of these scenes contained targets located on or near roads, while the remaining two contained targets placed distant from roads in the scene. The target combinations represented were a single tank, a group of 3 tanks, a convoy of 3 tanks, a group of 9 tanks, and a convoy of 9 tanks.

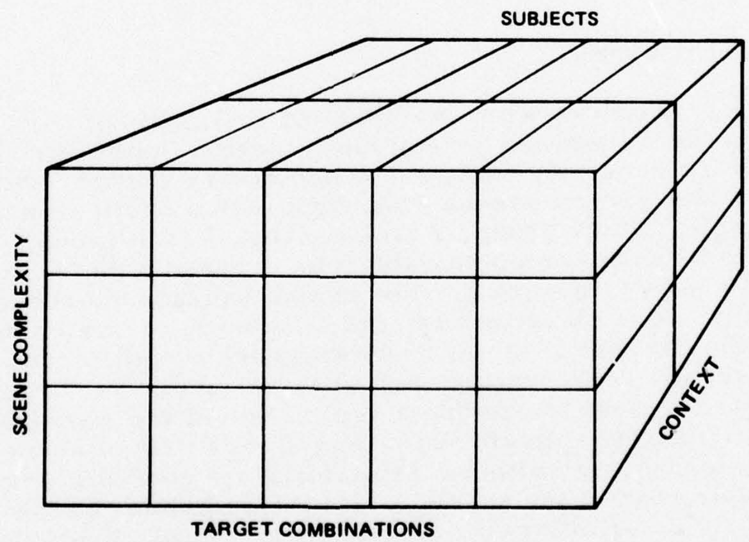
Five groups of subjects were shown all background scenes; however, any one group was presented scenes embedded only with a particular target combination. Subjects viewed target scenes which simulated an out-the-window, 30-degree field of view world, and attempted to locate the pre-briefed target combinations as quickly as possible within a 30-second time limit. Subjects' responses were scored as correct or incorrect, and time to correct detection was recorded. Incorrect responses were assigned the maximum allowable time.

EXPERIMENTAL DESIGN

Four variables were manipulated in a mixed design containing both independent (between-group) and repeated (within-group) measures. Subjects were randomly assigned to one of five groups, each of which was shown background scenes embedded with a particular target combination (single, 3 tank group, 3 tank convoy, 9 tank group, or 9 tank convoy). This between-group variable was crossed with the repeated measures, as shown in Figure 2. The twelve background scenes, shown to all subjects, were classified as high, medium, or low complexity, based on the Ciavarelli et. al.[12] heterogeneity scale (scene complexity). The four scenes representing each of these levels were randomly divided into two sets to provide a replication of the complexity classification (complexity replications). One of each pair of scenes representing a complexity level within a replication set contained targets on or near a major road in the scene, while the remaining scene contained targets in fields or otherwise distant from a road (local context). The between-group variable, then, was target combinations and the within-group variables were scene complexity, complexity replications, and local context.



COMPLEXITY REPLICATION 1



COMPLEXITY REPLICATION 2

FIGURE 2. Experimental Design.

STIMULUS MATERIALS

A total of 24 background scenes were chosen from a set of photographs provided by the Naval Weapons Center. Twelve were used as the experimental backgrounds, 10 were employed for training purposes, and the remaining two were targetless "catch" scenes. Targets were embedded as described in the following section.

The 12 experimental scenes were classified as representing high, medium, or low complexity levels based on paired-comparison heterogeneity scale values presented in the Ciavarelli, et. al. study.[12] The heterogeneity measure of complexity incorporated features such as texture variation, brightness, spacing and pattern variation into a relatively simple verbal description. Subjects based pair-by-pair complexity decisions on this description, and the rankings obtained by this method were transformed into scale values. For the purpose of the present study, scale ratings above 2.00 were considered to be highly complex, ratings between 1.39 and 1.99 were designated as medium complexity, and scenes with values below 1.39 were categorized as low complexity. This classification system yielded four examples of each level of complexity, for a total of 12 background scenes.

Two complexity replication sets were created by randomly assigning two of the four examples of each complexity level to a second set. By providing a replication based on the heterogeneity measure employed, the validity of this measure across different scenes could be assessed. In particular, results obtained with one set should be duplicated in the other, within limits of experimental error, if the heterogeneity measure is a valid assessor of scene complexity.

Five copies of each of the 12 experimental background scenes were prepared. One of the five target combinations (single tank, 3 tank group, 3 tank convoy, 9 tank group, and 9 tank convoy) was embedded in each for a total of 60 different scene-target slides. The 10 training slides were prepared so that each of the five target combinations was represented in two slides. In one the target combination appeared on or near a road, while in the other it was distant from roads.

Apparent direction of target movement was determined randomly within constraints imposed by terrain features of particular background scenes. This allowed a variety of aspect angles to be included in the experiment. Within a particular target combination, the tanks were evenly spaced to increase the probability that subjects responded to the entire number-configuration pattern rather than to an unintentional pattern produced by gestalt clustering. Across scenes and target combinations, however, target spacing and total visual angle subtended by the target combinations were not controlled, but instead were determined by scene background considerations. The orientation of individual tanks within a target combination was varied slightly to achieve greater realism.

All target combinations appeared at a constant range-to-target, simulating a real-world slant range of 1.3 kilometers. To avoid the possibility that subjects would learn to search a particular portion of the two-dimensional displayed scene, the apparent depression angle from which the photographs were taken was manipulated. Thus, although tanks appeared equal in angular subtense, their location with reference to the display center was varied.

In summary, the following parameters were held constant in the preparation of the experimental target scenes: altitude, field of view, target vehicle type, target range, angular subtense of an individual tank, and target spacing within a scene. Apparent depression angle, location within a scene, apparent direction of movement, and orientation within a target combination were determined by limits imposed by terrain features of particular scenes. In addition, the following factors were specifically manipulated: scene heterogeneity, target number-configuration combinations, and local context.

EMBEDDING PROCEDURE

The oblique aerial photographic imagery used in the present study was provided by the Naval Weapons Center. Details of the original photographic collection may be found in Ciavarelli, et. al.[12] A subset of 24 background scenes representing a variety of visual complexity levels was chosen from the pool provided. To meet the precision placement and size requirements of multiple target embedding, a photographic technique was developed in which images of Russian T-62 tanks could be overlaid on background images to form composite images.

The imagery provided was a series of contact negatives of photographs taken from an altitude of 305 meters and encompassing a 60-degree field of view. Detailed models of T-62 tanks (scale factor 1:285) were obtained and photographed to provide images for compositing. Because of visual acuity limitations, it was determined that an individual tank should subtend a minimum of 10 minutes of visual arc in the final viewing condition. To simulate an out-the-window view of 30 degrees and maintain the required visual subtense, the required tank placement range in the real world was calculated to be 1.3 kilometers. This distance was located in each negative, and a 30-degree field of view mask was placed on the film. This placement was varied across the negatives to vary target location within the final slide. Each masked negative was projected on a rear-projection screen, and a 35-mm photograph was taken with a Nikon F camera fitted within a 50-mm lens. The camera was placed so that the 30-degree field of view just filled the short dimension of the film. This procedure yielded film positives immediately upon developing, minimizing the required number of film processing generations.

The embedding technique was as follows. A frame was constructed and placed so that when a removable rear-projection screen was mounted in it and the background scene projected, the view through the camera duplicated the viewing angles of the original aerial photographs, but with the 30-degree field of view filling the short dimension of the film. A removable sheet of plexiglass was also placed in the frame. While viewing through the camera, the desired location of the targets to be embedded in each scene was marked on the plexiglass.

The rear-projection screen was then removed, and the frame apparatus was taken outdoors to use sunlight for the creation of realistic shadows. At the appropriate time of day, the frame apparatus was positioned to obtain the correct shadow length and direction for a particular scene. The model targets were then placed so that imaginary straight lines passed from the camera to the targets through the marks on the plexiglass. The plexiglass was removed when the targets were satisfactorily positioned, and a 35-mm photograph of the target array was taken. This procedure was repeated for each of the target combinations and background scenes.

The negatives of the target photographs were opaqued to remove all unwanted background surrounding the target vehicles. Film positives were then generated from the opaqued negatives, yielding 35-mm images of the targets on a clear background. These images were matched with the appropriate background scene images, and composites were formed by overlaying the two film positives. These were masked to a 2.5- x 2.5-cm format and mounted in metal and glass slides, which served as the experimental stimuli. An example of the embedded photographic imagery is presented in Figure 3, and a representative subset of the 60 embedded scenes is contained in Appendix A.

APPARATUS

Experimental target-background scenes were presented to subjects by means of a two-field projection tachistoscope, which consisted of two Kodak Carousal 35-mm slide projectors, two Gerbrands shutters (model G1166), a combining glass, and a rear-projection screen. Both projectors were focused within a 0.61-meter area of the projection screen. A control panel from which the shutters were controlled also provided a digital timer which had a synchronous onset with the opening of the stimulus shutter. The subject was provided a response key which stopped the timer, as well as a stylus to point out the location of the detected targets. A schematic presentation of the experimental configuration is shown in Figure 4.

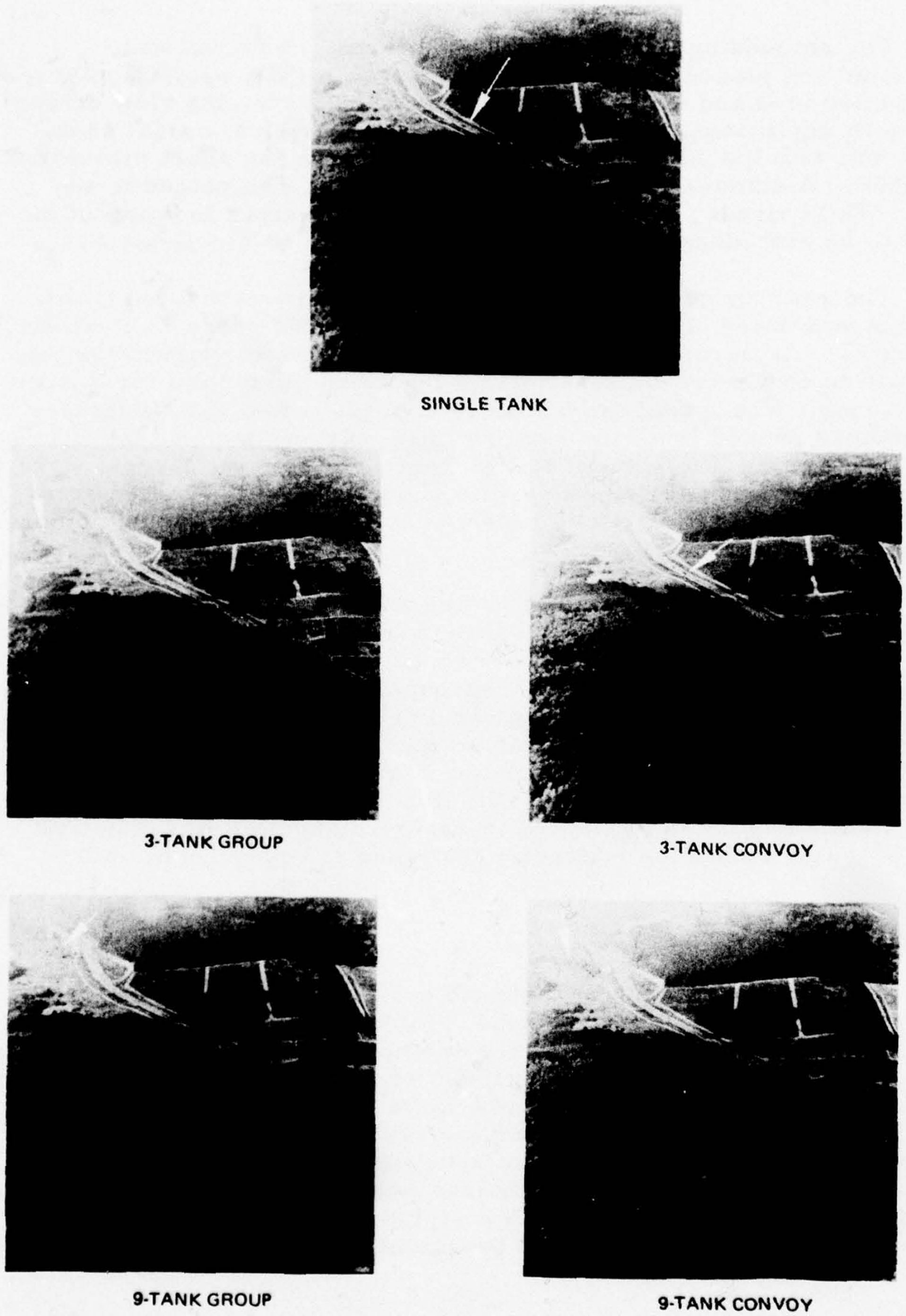


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FIGURE 3. Example of Target Number-Configuration Combinations.

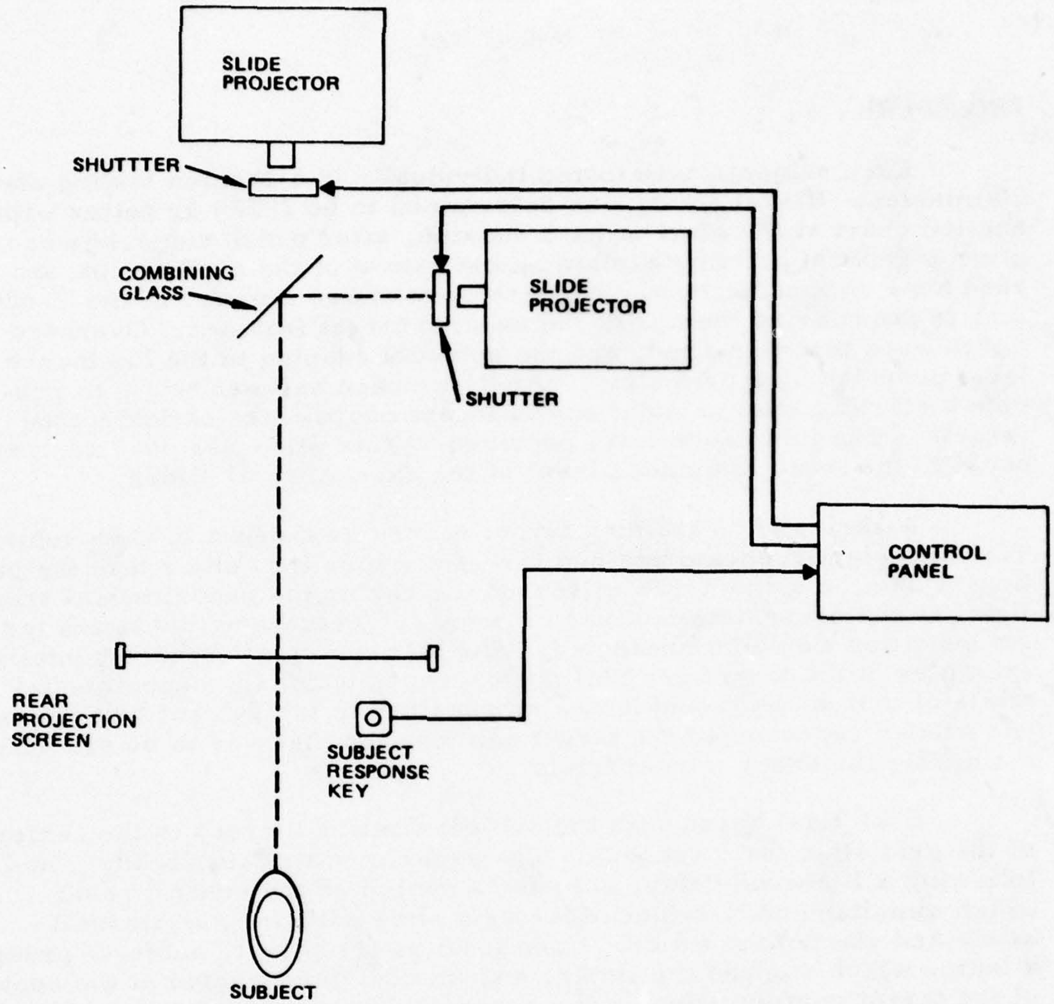


FIGURE 4. Schematic Diagram of Experimental Apparatus.

The rear-projection screen was set 1.14 meters from the subject's eye; at this distance the 0.61-meter display replicated an out-the-window, 30-degree field of view. Subject's heads were stabilized by a chin and forehead rest attachment to a table to maintain a constant viewing distance.

SUBJECTS

The subjects were 25 Hughes Aircraft Company employees who had corrected or uncorrected Snellen acuity of 20/20 or better. Each was randomly assigned to one of five target number-configuration groups.

PROCEDURE

Each subject participated individually in a session lasting about 20 minutes. Visual acuity was determined to be 20/20 or better with a Snellen chart at the start of each session, after which subjects were given a general briefing explaining the nature of the experiment, and then read a set of instructions. Subjects were shown a model of the T-62 tank to familiarize them with the general target features. Overhead lights were then darkened, and the subjects adapted to the luminance level provided by a grid slide, which was used between trials to provide a starting fixation point and to locate coordinates of designated targets. The luminance level provided by this slide was 36.7 cd/m^2, equal to the mean luminance level of the experimental slides.

A series of 10 training target scenes was shown to each subject. The first eight scenes contained target combinations other than the particular one the subject was to search for during the experimental trials. Prior to the presentation of each scene, subjects were told which target condition would be presented. The last two target scenes contained examples of the target combination appropriate for the experimental trials of that subject, and it was emphasized to the subject that the last two scenes represented the target combination that was to be searched for during the experimental trials.

Each trial began with the subject fixating a cross in the center of the grid slide for 5 seconds. The experimenter said "ready", and following a 1-second delay, actuated a switch on the control panel which simultaneously replaced the grid slide with an experimental scene and started the timer. Upon locating the target, subjects pressed a button which stopped the timer, and immediately pointed at the center of the target configuration on the screen. The experimenter replaced the scene with the grid slide, and the subject called out the coordinates of the stylus position. The experimenter recorded time to detection and the coordinates, advanced the slide projector containing the scene slides, and indicated the start of the next trial. A maximum 30-second viewing time was allowed on any trial.

Training and experimental trials were conducted similarly except that feedback was given to subjects during the training trials. Any training scene in which a target was missed was re-presented immediately, and the correct location was pointed out by the experimenter. No feedback of any kind was given to subjects during experimental trials.

Following the presentation of the 10 training scenes, the 14 experimental scenes were shown, two of which were targetless "catch" scenes. All experimental scenes shown to an individual subject contained only one type of target combination, which was pre-briefed and emphasized to the subject. Data were scored immediately following each individual session, and subjects were told the results of their performance at that time.

RESULTS AND DISCUSSION

The time and probability data were transformed by assigning all incorrect responses the maximum allowable time of 30 seconds. The data for each of the dependent variables were subjected to an analysis of variance, which was followed by a series of more detailed analyses performed to clarify the effects of the variables on detection performance. In particular, detailed analyses were performed on the effects of target number and target configuration, the effects of local context and its interaction with target combinations, and the effects of scene heterogeneity.

The results of the analysis of variance procedures are presented in Tables 1 and 2. Table 1 shows the results for the probability measure. The between-group variable, target combinations, was found to yield reliable differences. This was also found to be statistically significant in the analysis of the time to detection data, presented in Table 2. Of the three within-group variables, only local context was found to be statistically significant in both the time and probability analyses. The complexity replications variable was not statistically reliable, which indicated that the heterogeneity measure was internally consistent across different scenes. The heterogeneity measure itself, however, yielded contradictory results; no reliable effects on the probability of detection were found among scenes of different complexity levels, but statistically significant differences were obtained with the time to detection measure. This was further complicated by the presence of a reliable interaction between the heterogeneity and replications variables found with the time to detection data only, as well as higher-order interactions involving both variables found in each of the analysis of variance procedures. These results were subjected to a more detailed analysis and will be discussed in a separate section. A reliable interaction was found between target combinations and local context; significance was obtained in both analyses of variance. The nature of this interaction was also explored in a more detailed analysis and will be reported in a succeeding section.

TARGET NUMBER-CONFIGURATION COMBINATIONS

The cumulative probability of detection over time for the five target combinations is presented in Figure 5. The steeper slope found with increasing number of targets indicates superior performance in time to detection as the number of tanks present increases; this trend for improved performance with increasing number of targets is also indicated by the consistent ordering found in the final probabilities of detection. A series of <u>post hoc</u> comparisons by the Newman-Keuls

TABLE 1. Summary of Analysis of Variance Results: Probability of Detection

Source of Variance	df	Error Term	Mean Square	F-Ratio	Probability Level
Between Groups					
T (Target Combinations)	4	S	1.61	7.77	<0.001
Within Groups					
L (Local Context)	1	LS	1.33	10.00	<0.01
H (Heterogeneity)	2	HS	0.13	1.28	NS
R (Complexity Replications)	1	RS	0.00	0.00	NS
Interactions					
TL	4	LS	0.79	5.94	<0.01
TH	8	HS	0.36	3.49	<0.01
TR	4	RS	0.18	1.94	NS
LH	2	LHS	0.24	3.84	<0.05
LR	1	LRS	0.01	0.08	NS
HR	2	HRS	0.21	1.50	NS
TLH	8	LHS	0.48	7.53	<0.001
TLR	4	LRS	0.22	1.36	NS
THR	8	HRS	0.56	4.00	<0.01
HLR	2	HRLS	0.44	3.21	NS
THLR	8	HRLS	0.30	2.18	<0.05
Error Terms					
S	20		0.21		
LS	20		0.13		
HS	40		0.10		
RS	20		0.09		
LHS	40		0.06		
LRS	20		0.16		
HRS	40		0.14		
HLRS	40		0.14		

TABLE 2. Summary of Analysis of Variance Results: Time to Detection

Source of Variance	df	Error Term	Mean Square	F-Ratio	Probability Level
Between Groups					
T (Target Combinations)	4	S	1521.30	11.32	<0.01
Within Groups					
L (Local Context)	1	LS	871.43	10.76	<0.01
H (Heterogeneity)	2	HS	229.58	3.66	<0.05
R (Complexity Replications)	1	RS	3.97	0.09	NS
Interactions					
TL	4	LS	794.09	9.81	<0.001
TH	8	HS	256.71	4.10	<0.01
TR	4	RS	59.26	1.34	NS
LH	2	LHS	216.68	6.04	<0.01
LR	1	LRS	0.47	0.01	NS
HR	2	HRS	391.41	4.95	<0.05
TLH	8	LHS	523.50	14.58	<0.001
TLR	4	LRS	281.39	3.16	<0.05
THR	8	HRS	317.98	4.02	<0.01
HLR	2	HLRS	224.24	4.04	<0.05
THLR	8	HLRS	261.14	4.70	<0.001
Error Terms					
S	20		134.42		
LS	20		80.98		
HS	40		62.65		
RS	20		44.24		
LHS	40		35.90		
LRS	20		88.99		
HRS	40		79.14		
HLRS	40		55.54		

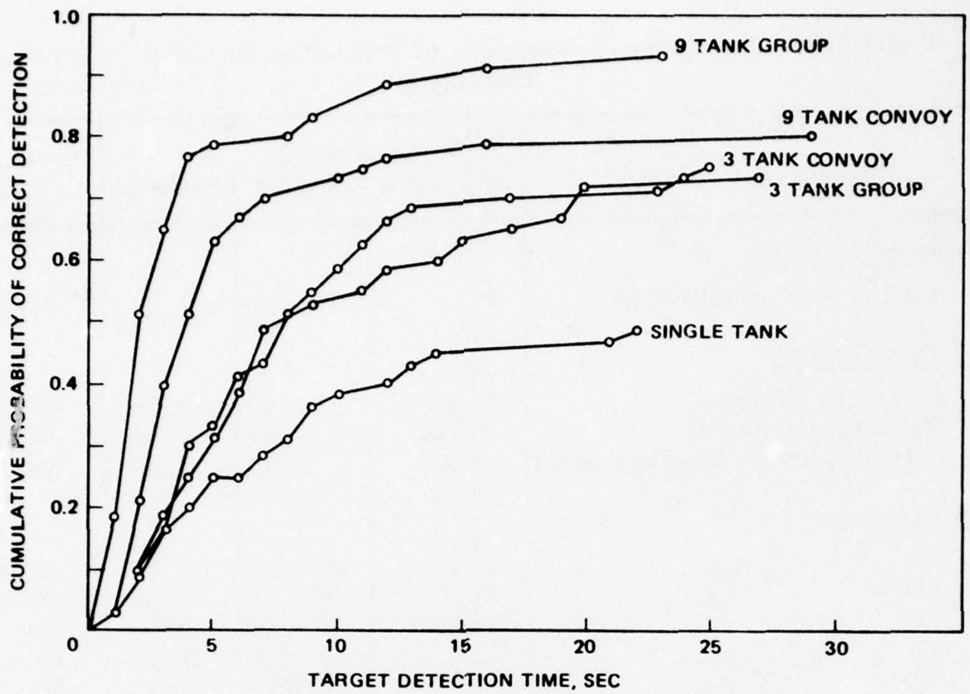


FIGURE 5. Cumulative Probability of Detection Over Time for Target Number-Configuration Combinations.

critical range method performed on differences among target combinations indicated an interesting interaction of number and configuration. Configurational differences were not evident when only three tanks were present ($p > 0.10$), but a slight advantage in detection of groups over convoys was found with 9 tanks ($p = 0.054$). Further evidence for the reliability of this interaction was obtained from the results of a series of paired comparisons performed among the two configurations containing three tanks and the two containing nine. Neither of the configurations containing three tanks was significantly different from the 9 tank convoy condition ($p > 0.10$), but both produced reliably poorer performance than that found with the 9 tank group condition ($p < 0.05$). This was true for both the time and probability data.

It appears likely that this configurational advantage found with nine tanks reflects a difference in the overall angular subtense in the group and convoy conditions. Inspection of the target scenes indicated that with the 30-degree field of view, more than one fixation was generally required to view an entire convoy of nine tanks, while groups of nine were, for the most part, clustered tightly enough to be fully viewed

in one fixation. All of the convoys subtended more than 6 degrees of visual angle (extending into the perifoveal region), while more than 60 percent of the group configurations subtended less than 3 degrees, and no group subtended more than 4 degrees (within the parafoveal region). Because little information is extracted from the peripheral and perifoveal regions during a fixation[8], it can be argued that more target vehicles were visible for a given fixation in the 9 tank group configuration than in the 9 tank convoy condition. Thus, by the argument that an increased number of targets perceived as a pattern in a single fixation should increase detection performance[9], an explanation for the configurational differences found with nine tanks is possible. This line of reasoning is supported by the increase in performance found between a single tank and both configurations containing three tanks, all of which fall within the parafoveal or the foveal areas. The larger number of tanks visible in a single fixation in the configurations containing three tanks leads to the prediction of superior performance, and this expectation is confirmed by the data. Extension of this argument leads to the prediction that a still greater increase should be found in the 9 tank group condition, but not in the 9 tank convoy condition in which the critical area is exceeded. Results found with the 9 tank convoy condition should in fact more closely resemble those found with three tanks. The data are entirely consistent with the predictions generated by this reasoning, and it was concluded that the advantage found with groups of nine over convoys of nine was caused by the differences in angular subtense between the two configurations.

LOCAL CONTEXT

Across all target combinations, a reliable improvement in performance was found when targets were located on or near roads. This can be clearly seen in Figure 6, which plots cumulative probability of detection over time. The effect of local context, however, is dependent on the number of tanks in a configuration. The interaction of local context and target combination identified in the analysis of variance was found to be due to the number of tanks present and not due to configuration. The data were therefore averaged over configuration and are presented in Figure 7 as an interaction between local context and the number of target vehicles. The effect of local context was minimal when multiple tanks were present, but created a large difference in performance when the target was a single tank.

It can be seen in Figure 7 that a pronounced advantage in performance is found when single tanks are on or near roads. This performance difference disappears with multiple tanks, and probability of detection over time in these target combinations is virtually identical for targets on and off roads. An interesting difference is found by examination of the data for the single and multiple target conditions within the first 5-second period. When a single target is located on a road,

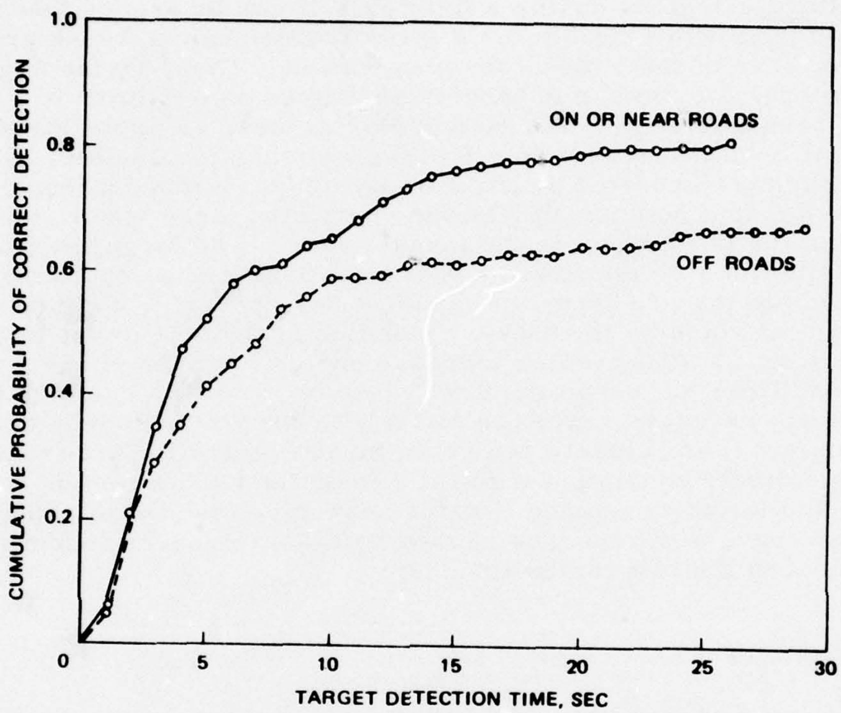
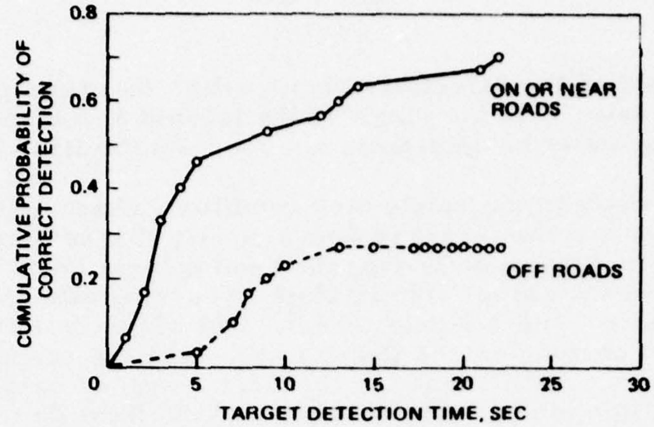
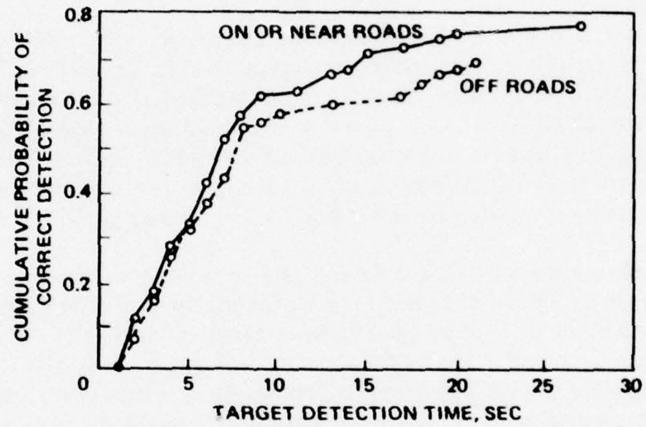


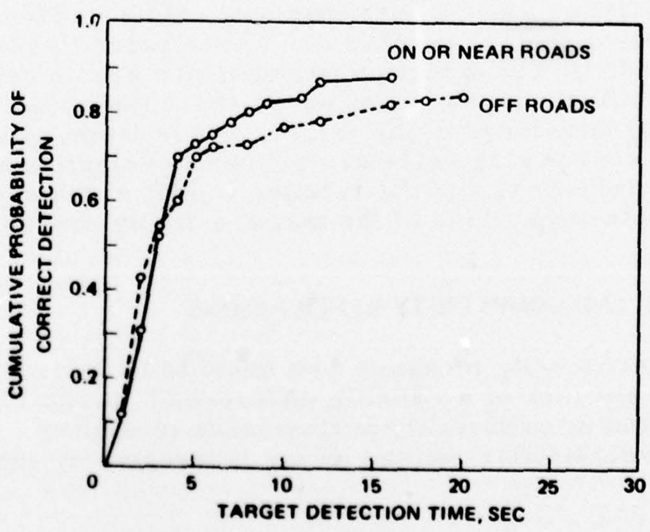
FIGURE 6. Effect of Local Context on Detection Performance.



a. Single tank.



b. Three tanks.



c. Nine tanks

FIGURE 7. Interaction of Local Context with Target Number.

over 50 percent of the detections occur within that time period. This is to be contrasted with the single tanks located at a distance from a road where virtually no detections are made in the first 5 seconds.

Apparently in the single tank condition, observers search roads preferentially, and the target is found quickly if it is there. If it is not, other areas are subsequently searched and targets begin to be found, which produces the abrupt rise in slope occurring after 5 seconds in the off-road condition with a single target. The virtually flat slope in the first 5-second period denotes the time subjects are spending fruitlessly searching roads. A difference in the first 5-second period is not evident with multiple tanks, which argues that subjects do not find roads strong cues in these conditions. The lack of any difference in the first 5 seconds indicates that subjects have changed their search strategy, and roads are not searched preferentially.

It is possible that with multiple targets, the pattern itself is so salient that it is more efficient to search for it directly, with less regard to cues provided by the background scene. Alternatively, it is possible that the salient scene cues simply change as a function of knowledge about the expected number of targets. Open areas large enough to contain that number of tanks might be located first, or areas of high clutter density may be salient, particularly for groups of nine.

It cannot be determined from the results of the present study just what shift in search strategy is caused by *a priori* knowledge about the number of targets, but it is evident that it occurs. Roads are strong scene cues when a single target is to be located, but their saliency diminishes as the expected number of targets increases. However, it is not known what scene cues, if any, replace roads as areas to be preferentially searched. This result is indicative of the many complex scene-target interactions which make performance prediction on the basis of scene characteristics alone a less than optimal procedure. When target characteristics such as number are known prior to search, their inclusion in prediction of detection performance seems necessary to evaluate the relative importance of scene characteristics. However, when no *a priori* knowledge of the targets is available, it is reasonable to assume that search strategies are primarily determined on the basis of scene characteristics, and the relative weight of these characteristics will be stable regardless of the target actually present in the scene.

HETEROGENEITY AND COMPLEXITY REPLICATIONS

The heterogeneity measure was found to be internally consistent as indicated by the lack of a reliable difference between replication sets on either the time or probability performance measures. That is, different scenes with similar ratings on the heterogeneity scale yielded

similar performance. However, the external validity of the heterogeneity measure was not demonstrated by the data.

No reliable differences in probability of detection were found for the three levels of heterogeneity, and a marginally reliable difference was found for the time to detect measure. The results of a series of Newman-Keuls post hoc comparisons revealed that the significant effect found with the time data was due to the difference between the high and low heterogeneity levels ($p < 0.05$). The actual difference in seconds, however, was quite small; this can be seen in Table 3, which presents the mean time and probability data for each of the three heterogeneity levels.

TABLE 3. Mean Time and Probability of Detection as a Function of Heterogeneity Level

Response Measure	Heterogeneity Level		
	Low	Medium	High
Time (Sec.)	10.73	11.56	13.68
Probability	0.78	0.73	0.71

Because the low, medium, and high heterogeneity categories did not contain ratings that were widely separated, it was possible that the artificial categorization of a continuous scale obscured a more pronounced effect. The actual heterogeneity ratings for each scene were, therefore, correlated with the time performance obtained for each scene. The resultant correlation across all target conditions was 0.18, which was not statistically significant ($p > 0.10$). This non-significant correlation provides evidence that the marginally significant differences found in the time analysis of variance procedure will not in fact make an important difference. The correlational analysis is in agreement with the probability analysis of variance results, which indicate that the heterogeneity measure of background complexity is not a valid predictor of detection performance.

Additional evidence for the inadequacy of the heterogeneity measure is illustrated in Figure 8, which represents the interactions of heterogeneity levels with the target combinations. The data presented are for the probability measure of performance, although the time to detection data are similar. It can be seen that performance on scenes of differing heterogeneity levels was not independent of the target combinations, inconsistent with what would be expected with a valid measure of background characteristics.

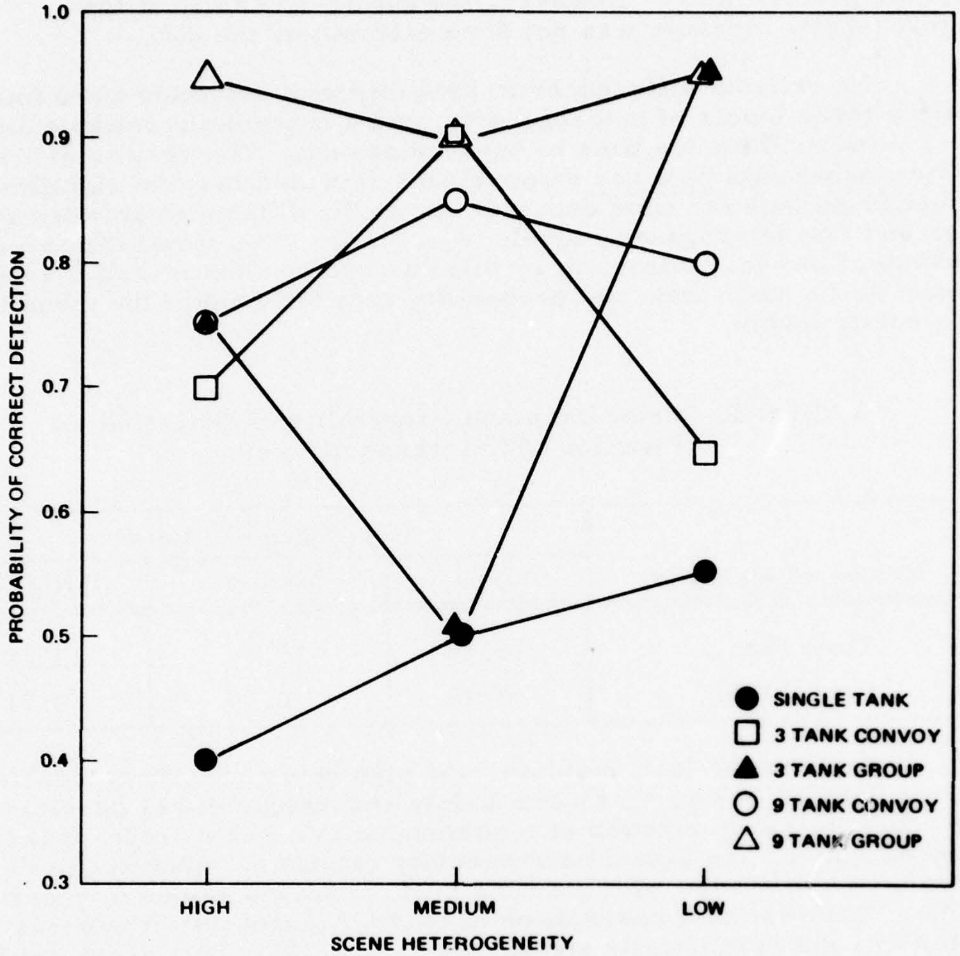


FIGURE 8. Interaction of Heterogeneity Level with Target Number-Configuration Combinations.

A further problem lies in the interpretation of the interaction, which is not systematic with respect to any of the manipulated variables. To clarify the nature of this interaction, a correlational analysis was performed between the heterogeneity ratings for each scene and the probability of detection in each target combination. These data are presented in the body of Table 4. The results of the correlational analysis for each target combination are listed in the bottom row. No significant correlations were found in any target combination; in addition, while negative correlations were expected (high heterogeneity leading to low probability of detection), this was only found in the 3 group conditions.

TABLE 4. Correlational Analysis Between Heterogeneity Ratings and Probability of Detection

Replication Set	Slide	Hetero. Rating	Target Number-Configuration Combination					Total
			Single	3 Group	3 Convoy	9 Group	9 Convoy	
1	55	2.42	0.80	0.80	0.60	1.00	0.40	0.72
	78	2.23	0.60	0.80	0.20	0.80	1.00	0.68
	81	1.61	0.00	0.20	1.00	1.00	1.00	0.64
	87	1.46	0.80	1.00	1.00	1.00	0.80	0.92
	23	1.25	0.80	1.00	1.00	1.00	1.00	0.96
	89	0.30	0.20	0.80	0.40	1.00	0.20	0.52
2	37	2.27	0.20	0.80	1.00	1.00	0.60	0.72
	70	2.03	0.00	0.60	1.00	1.00	1.00	0.72
	53	1.68	0.60	0.20	0.80	0.60	0.80	0.60
	75	1.39	0.60	0.60	0.80	1.00	0.80	0.76
	6	1.38	1.00	1.00	1.00	1.00	1.00	1.00
	71	0.00	0.20	1.00	0.20	0.80	1.00	0.64
Correlations			0.17	-0.27	0.37	0.08	0.04	0.16

It was concluded from these results that the heterogeneity measure of scene complexity is an inadequate independent predictor of detection performance and is not reliable even when scene-target interactions are taken into account. The significant higher order interactions isolated in the analyses of variance which included the heterogeneity variable were therefore considered suspect, and not subjected to further analysis.

It is evident from the detection probabilities averaged across all target combinations, presented in the last column of Table 4, that although the scene complexity measure employed was was not reliable, large differences are found among the individual scenes independent of target condition. This suggests that some set of scene characteristics, not measured by the heterogeneity scale, exists and may be used as an independent predictor of detection performance. The problem of identification of these variables still remains, as does the creation of a scale that is quickly and easily used in the field.

One problem with the heterogeneity measure may be that while it appears to be a global, unidimensional concept, it in fact encompasses judgments along several different dimensions and requires the observer

to integrate them subjectively before responding. Features that may appear to the observer to increase the "busyness" of a scene and make it more difficult to find a target may in fact be excellent cues to areas having a high probability of containing a target. The heterogeneity measure does not give the observer guidelines as to which features of a scene should be included in a subjective rating. In addition, no algorithm is provided to the subject for combining these features. An observer cannot be expected to understand the function of each scene characteristic well enough to subjectively combine it with all others in a useful fashion.

A more fruitful approach would be to identify each of the relevant features very specifically for the observers, allow judgments to be made along independent dimensions, and then to provide the observer with a specific algorithm for integrating the multiple dimensions. The first step in this approach entails the identification of the relevant parameters and the development of a reliable and valid objective measure for each. This provides a base from which a semantic-differential type of scale may be developed for use in the field. In addition, an objective, quantitative measure will allow the development of a regression equation or similar simple model which effectively combines the values obtained on each measure. This approach allows for the inclusion of target variables if they are available to the observer; a different set of weights would be used in the combining algorithm when such information is applicable.

CONCLUSIONS AND RECOMMENDATIONS

It is evident from the results of the present study that scene and target characteristics both singly and in combination greatly influence detection performance. A brief summary of these results is presented below, followed by a possible approach to solving the problem of creating prediction algorithms that use available information, remain viable with minimal information, and are easily used in a field situation.

TARGET EFFECTS

Target number provided the most consistent effect, with performance increasing as target number increased. This function described a negatively accelerating curve, however, and it is likely that little increase in performance would be found with numbers greater than the maximum of nine investigated in the present study. Configuration produced an effect only when nine tanks were presented, and these results were interpreted in terms of the angular subtense difference between groups and convoys.

The location of targets in relation to major roads in a scene yielded a reliable interaction with target number. Detection performance was significantly better when a single target was on or near a road, but no difference was evident with 9 tanks. It was proposed that this target number-context interaction signified a change in search strategy due to prior knowledge about target characteristics. In particular, certain scene characteristics acquired more or less efficacy in determining where the observer's attention would be directed. In particular, it appeared that roads became less important cues as the number of targets increased, and other features of the scene such as open areas may have replaced them in relative importance for determining search sequence.

It was further suggested that cue saliencies are determined primarily by scene characteristics if no prior information about target number is available, and these characteristics may be used reliably to predict detection performance in that situation. Additional accuracy in prediction may be provided by differential cue weighting functions when information about target characteristics is available.

SCENE CHARACTERISTICS

Reliable predictions of detection performance on the basis of scene characteristics demand a valid measure or set of measures with which to evaluate terrain. The heterogeneity measure used in the

present study did not provide an adequate assessment instrument. It did not predict performance either when used alone or when used in conjunction with target characteristics. The major factors appearing to contribute to its failure are:

a) Lack of specificity

b) Forced subjective integration into unidimensionality

c) Reliance on subjective comparison among scenes rather than on quantitative, objective metrics.

To correct these deficiencies, it is proposed that a set of specific, well-defined measures be developed to evaluate scene characteristics which have been found to be relevant to the prediction of detection performance. These measures will have a quantitative basis originally, but will be translated into an easily used set of verbal scales which produce judgments that correlate highly with the objective metric result, and may be combined in a relatively simple way to predict detection performance. A systematic approach to identify these dimensions, objectively measure them, and ultimately provide easily used scales on which to evaluate them is outlined below.

MULTIDIMENSIONAL APPROACH

The approach described briefly below is based on the assumption that an adequate assessment of scene characteristics requires a multidimensional set of scales, each of which makes a maximally orthogonal contribution to the prediction of detection performance. Many candidate factors have been proposed in previous studies, and additional characteristics may be determined by scene analysis and factor analytic techniques. For any given terrain, the values obtained on each of these scales can be combined in a simple weighting algorithm or multiple regression equation to generate a detection probability and/or time estimate. The weighting function may be modified to include available information on target characteristics. The major elements necessary to implement the proposed approach are as follows:

a) Identification of relevant scene characteristics

b) Development of objective measures

c) Development of descriptive scales

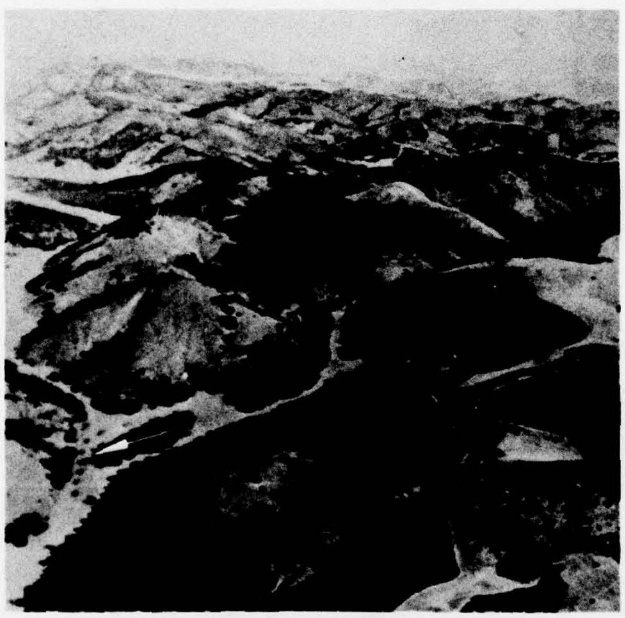
d) Development of model or algorithm for combining scene characteristics.

APPENDIX A

EXAMPLES OF EMBEDDED TARGET SCENES

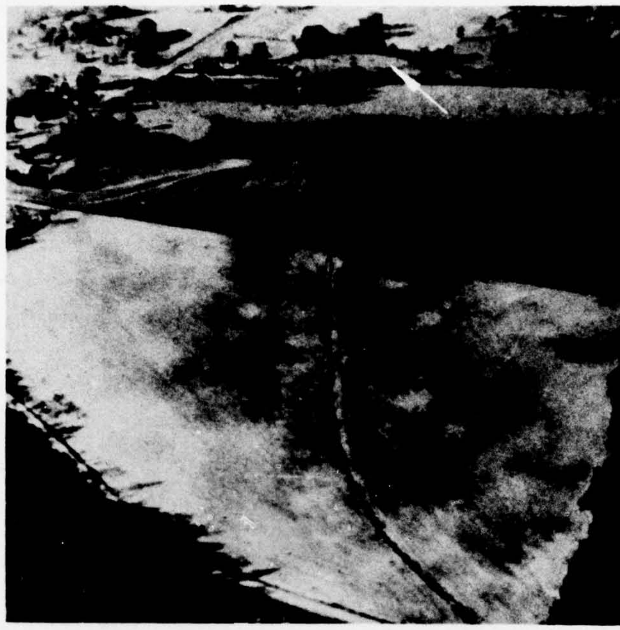
TA/4817

a. Target: Single tank
Context: On/near road

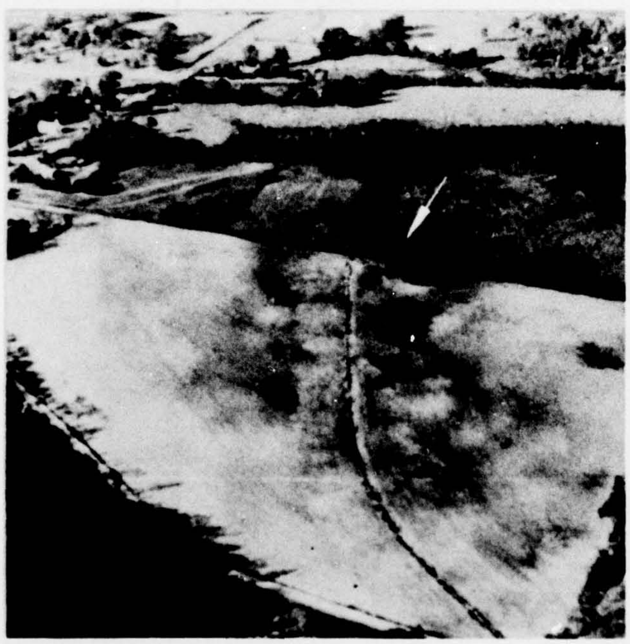


b. Target: 9-tank convoy
Context: On/near road

Slide 70
Heterogeneity Level: High

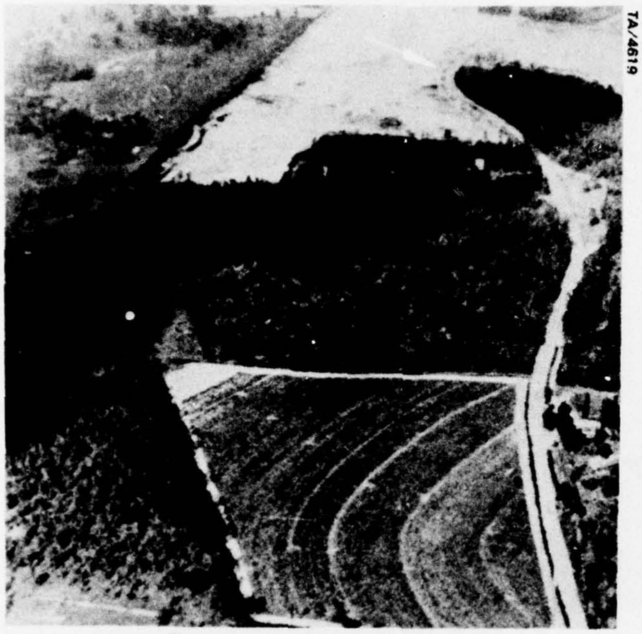


a. Target: 3-tank group
Context: Off road

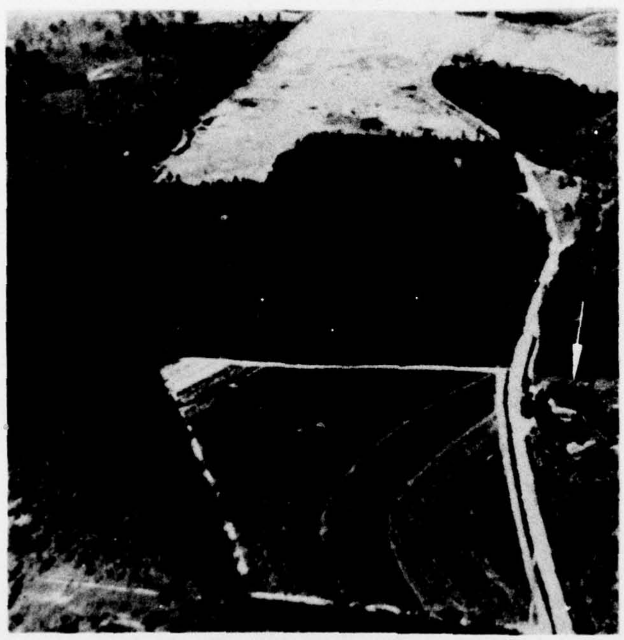


b. Target: 3-tank convoy
Context: Off road

Slide 37
Heterogeneity Level: High



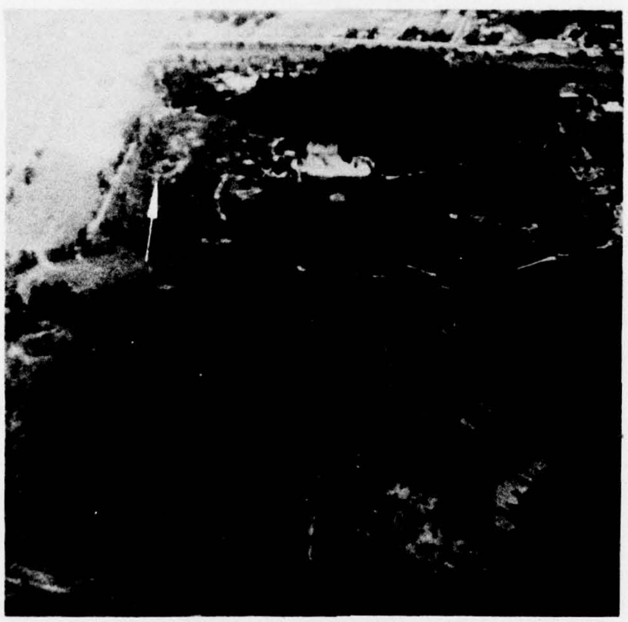
a. Target: 9-tank convoy
Convoy: On/near road



b. Target: 3-tank convoy
Context: Off road

Slide 78
Heterogeneity Level: High.

a. Target: 9-tank group
Context: On/near road



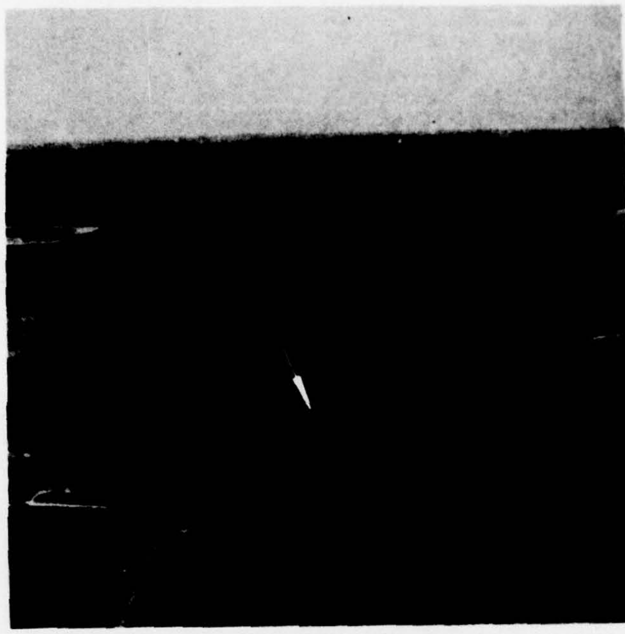
b. Target: 3-tank group
Context: Off road

Slide 55
Heterogeneity Level: High

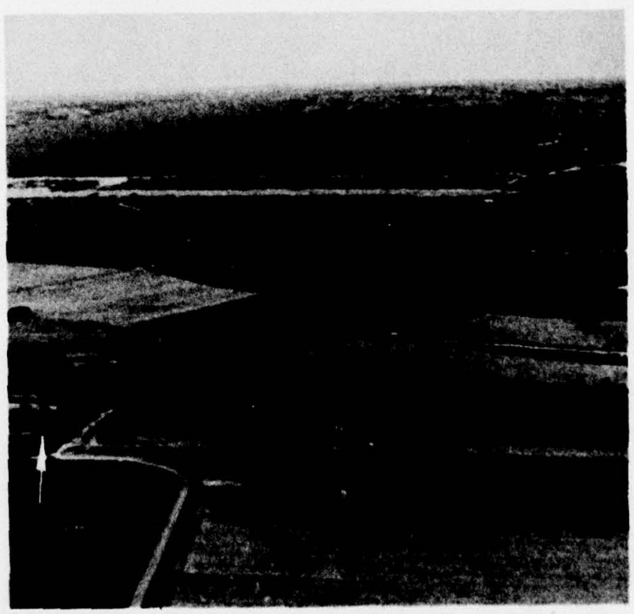
a. Target: 9-tank group
Context: On/near road

b. Target: 9-tank convoy
Context: Off road

Slide 53
Heterogeneity Level: Medium

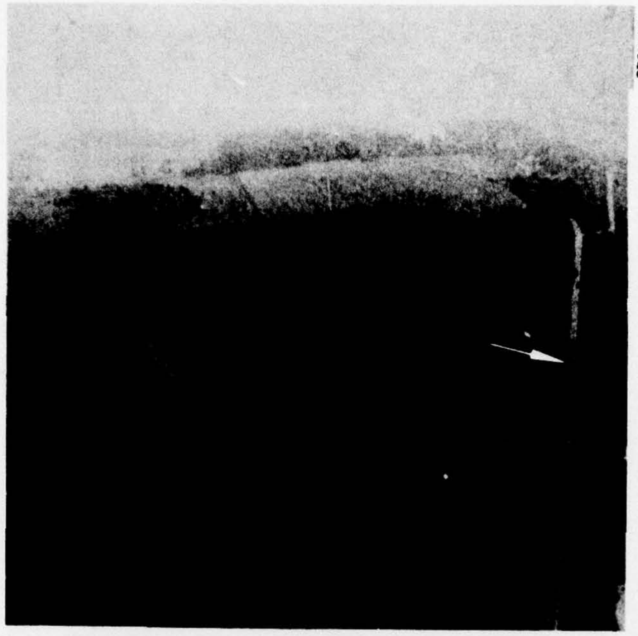


a. Target: 3-tank convoy
Context: Off road

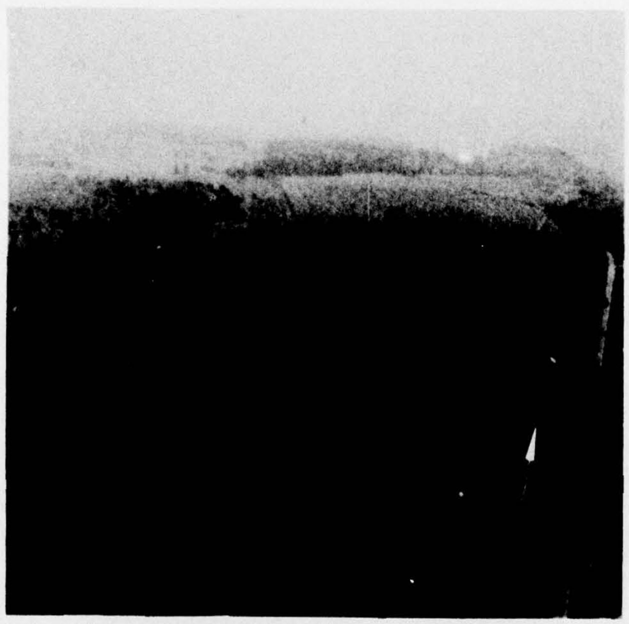


b. Target: 3-tank group
Context: On/near road

Slide 75
Heterogeneity Level: Medium

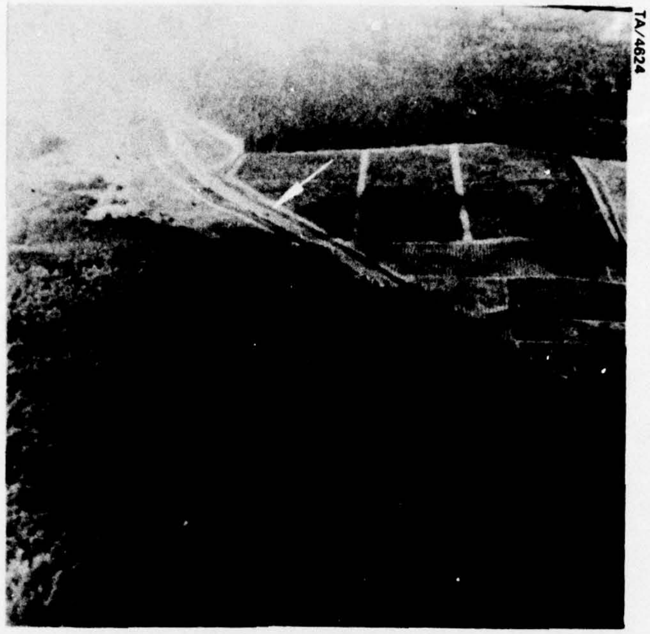

TA/4623

a. Target: 3-tank convoy
Context: On/near road

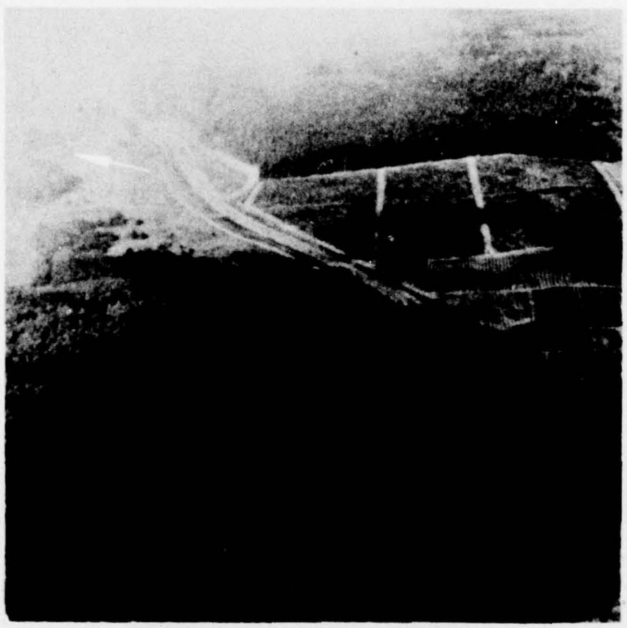


b. Target: 9-tank group
Context: On/near road

Slide 87
Heterogeneity Level: Medium

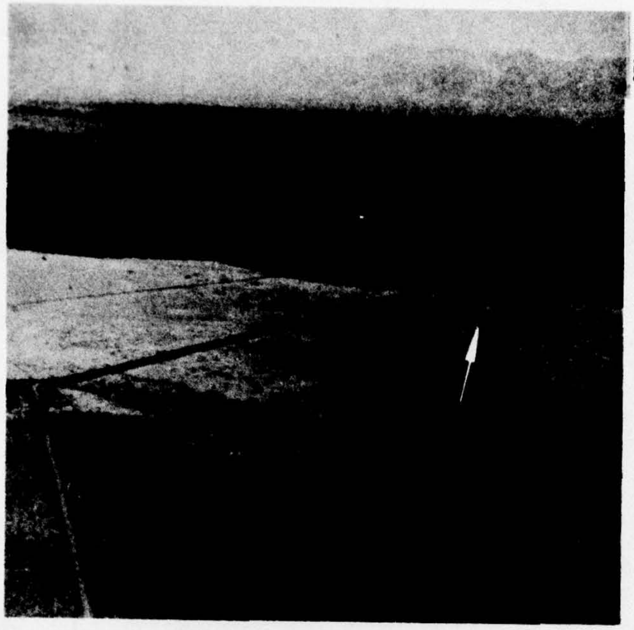


a. Target: Single tank
Context: On/near road

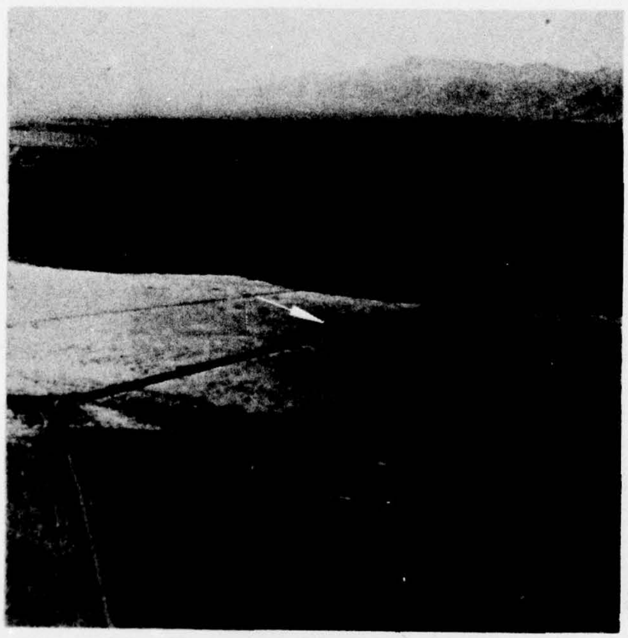


b. Target: 3-tank group
Context: Off road

Slide 23
Heterogeneity Level: Low



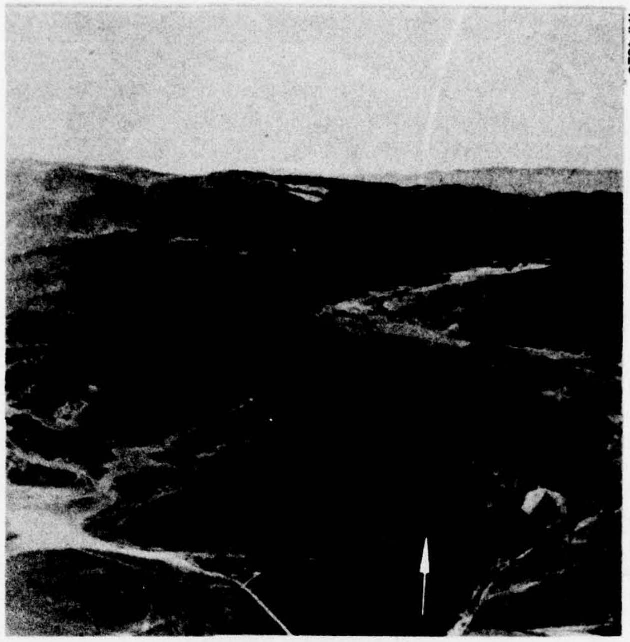
a. Target: 9-tank group
Context: On/near road



b. Target: Single tank
Context: On/near road

Slide 6
Heterogeneity Level: Low.

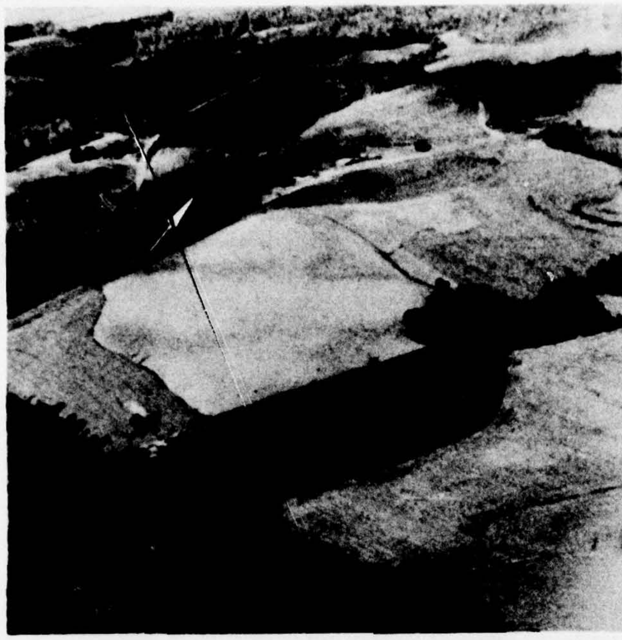
TA/4626



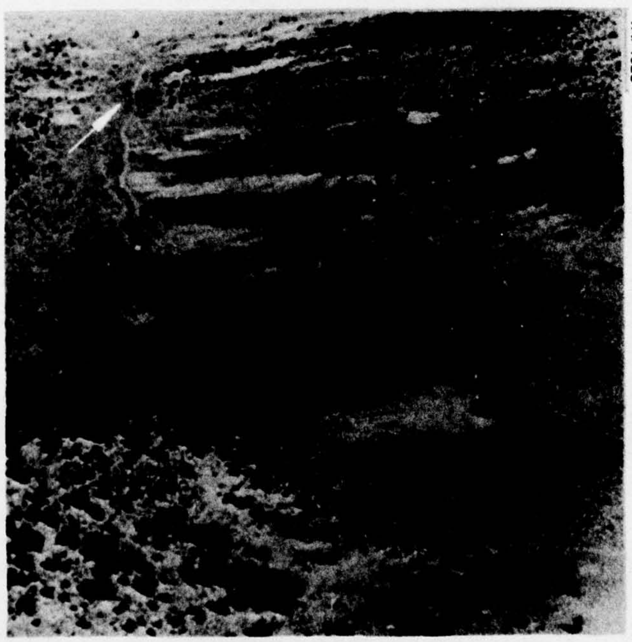
a. Target: 9-tank group
Context: Off road

b. Target: 9-tank convoy
Context: On/near road

Slide 71
Heterogeneity Level: Low.



Slide 81
Heterogeneity Level: Medium
Target: 9-tank convoy
Context: On/near road



Slide 89
Heterogeneity Level: Low
Target: 3-tank group
Context: On/near road

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